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**Morgante et al.**

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(54) **ELECTRIC MOTOR AND STATOR COOLING APPARATUS**


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***H02K 3/24*** (2006.01)
(Continued)

(52) **U.S. Cl.**
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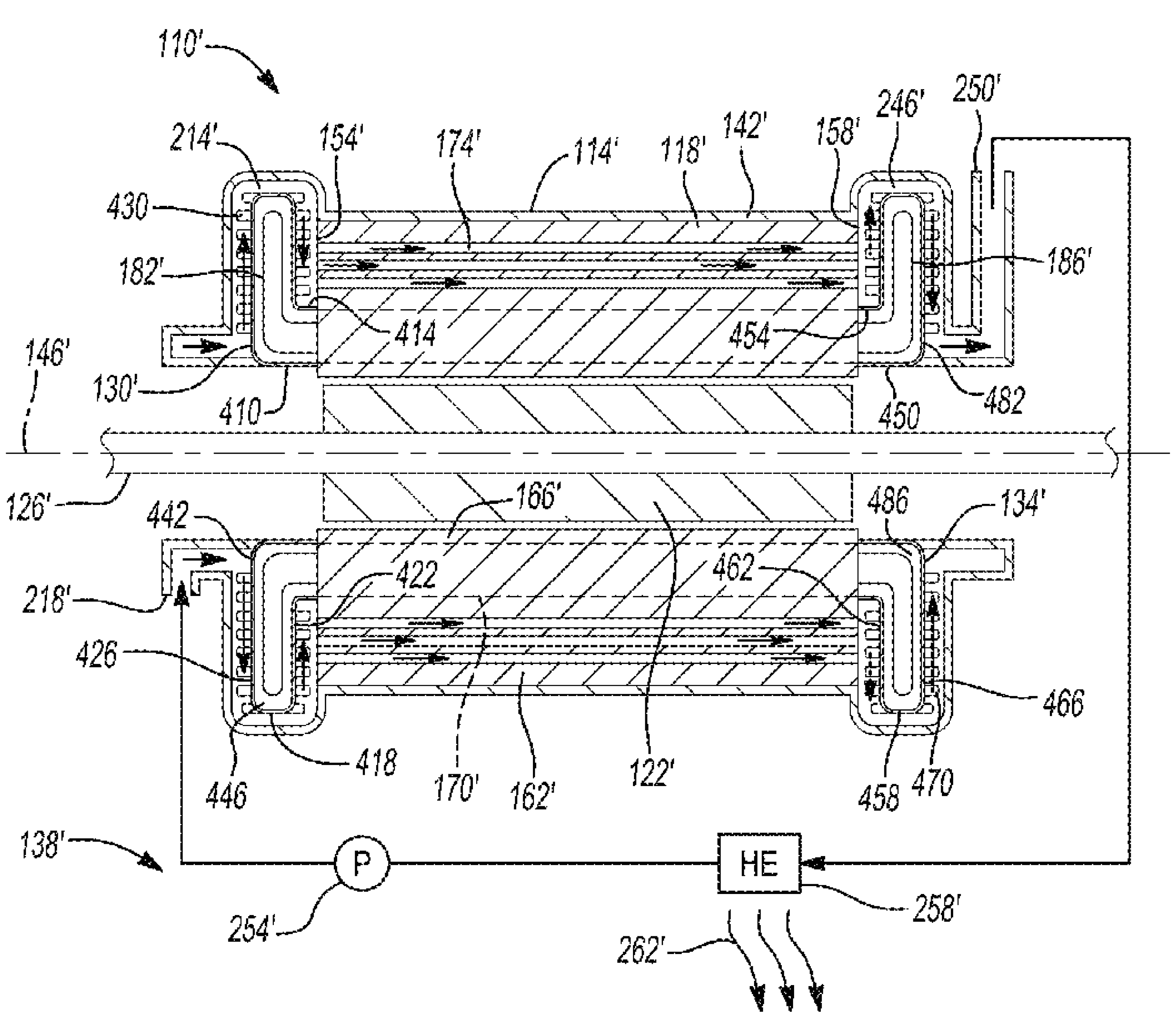
(57) **ABSTRACT**


An electric motor can include a stator body defining fluid channels extending axially for fluid communication between axial ends of the stator body. Conductive windings can form first loops extending axially outward from the first end of the stator body and second loops extending axially outward from the second end of the stator body. A first cap can be coupled to the first end of the stator body and can include a first wall. The first wall can be between the first loops and the channels. Pins can extend from a side of the first wall that is opposite the first loops. The second cap can be coupled to the second end of the stator body and include a second wall. The second wall can be between the second loops and the channels. Pins can extend from a side of the second wall that is opposite the second loops.


**20 Claims, 5 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. 15/820,934, filed on Nov. 22, 2017, now Pat. No. 10,879,749.

(51) **Int. Cl.**

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|---|---|
| ***H02K 5/20*** | (2006.01) |
| ***H02K 9/19*** | (2006.01) |
| ***H02K 9/197*** | (2006.01) |

(58) **Field of Classification Search**

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See application file for complete search history.

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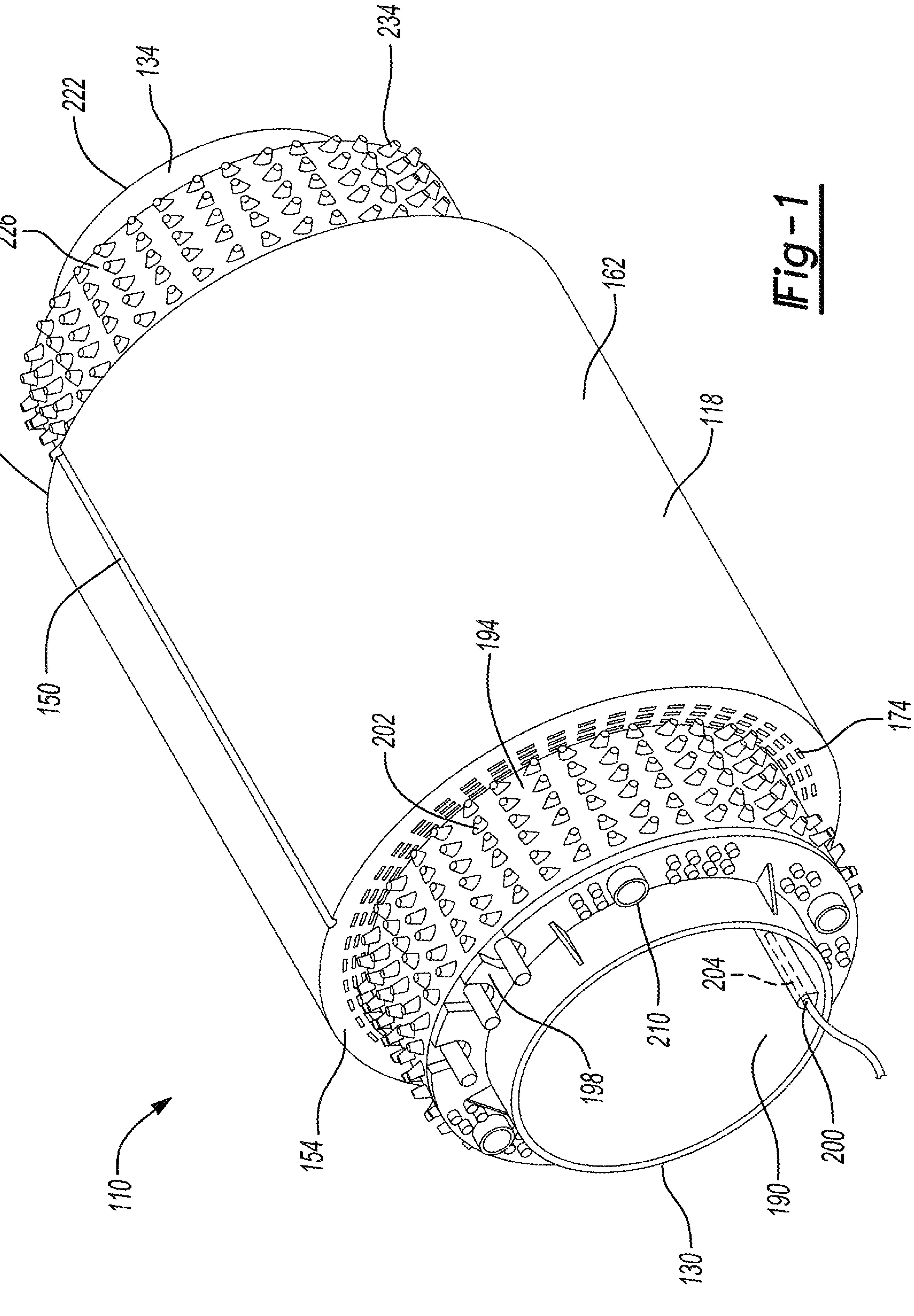

234
134
222
226
158
162
118
150
194
202
174
204
210
198
200
190
154
110
130

Fig-1

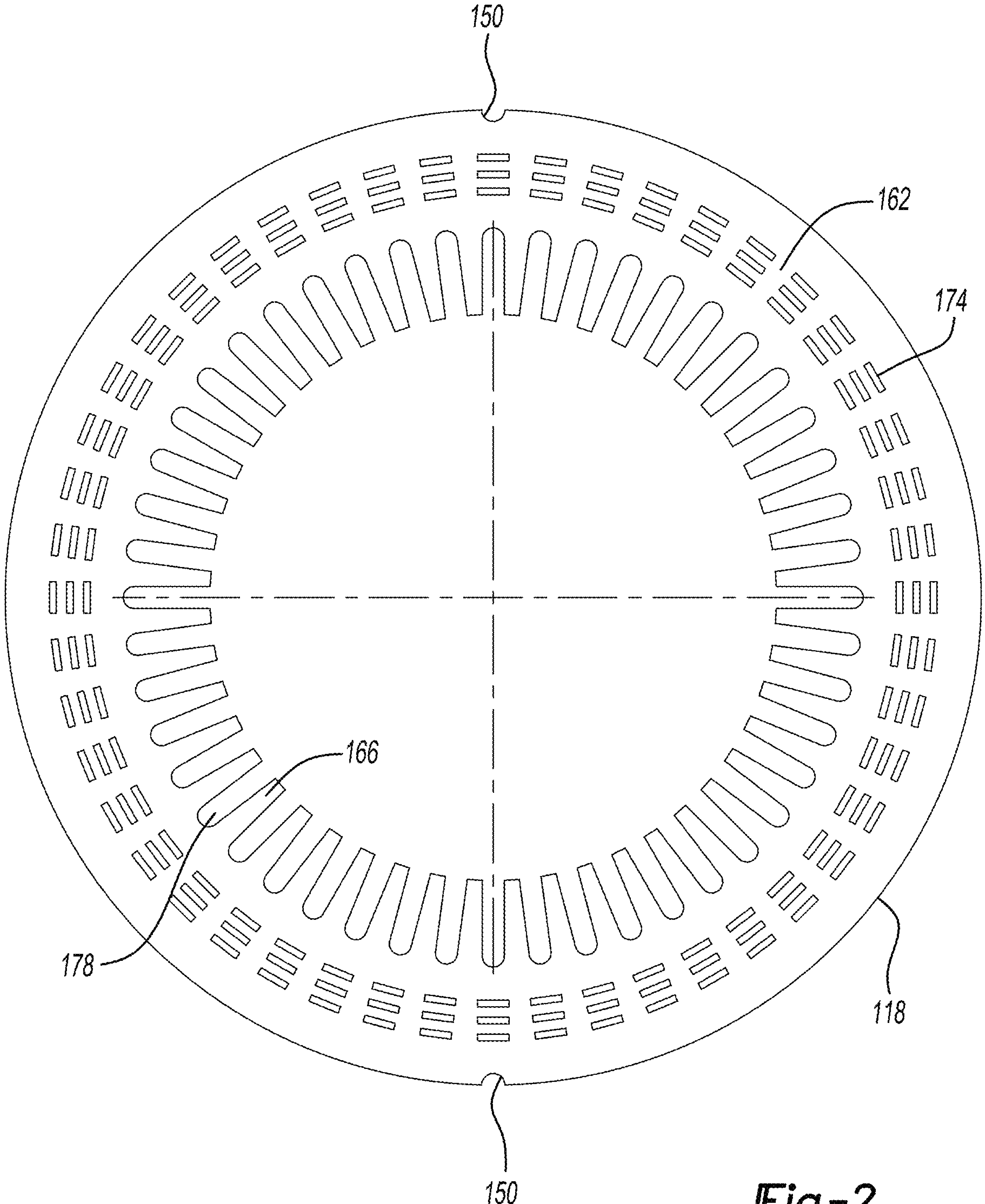



Fig-2

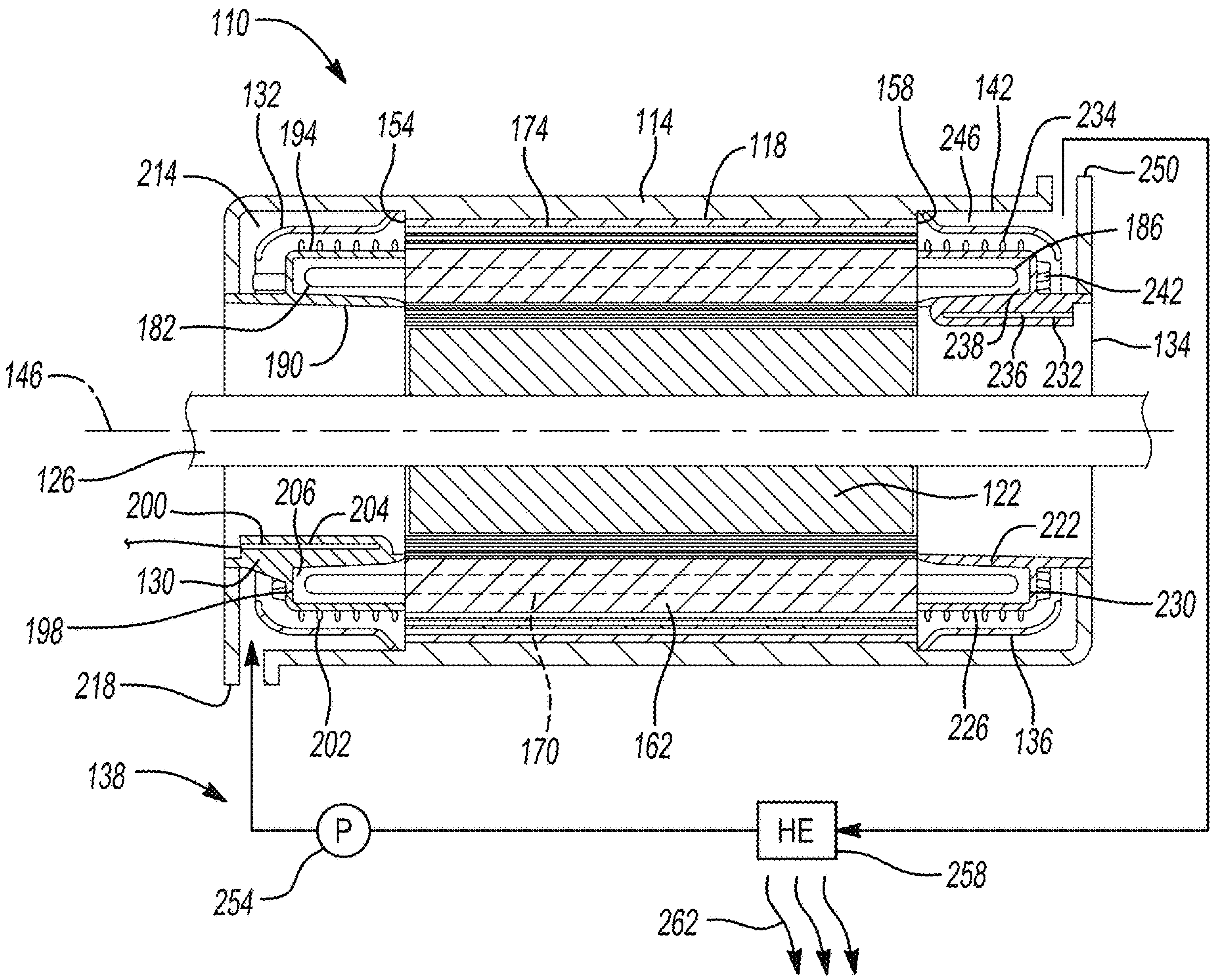

110
132
194
154
174
114
118
158
142
234
246
250
186
214
242
182
238
134
190
236
232
146
126
122
200
206
204
222
130
230
198
218
202
170
162
226
136
138
P
HE
254
258
262

Fig-3

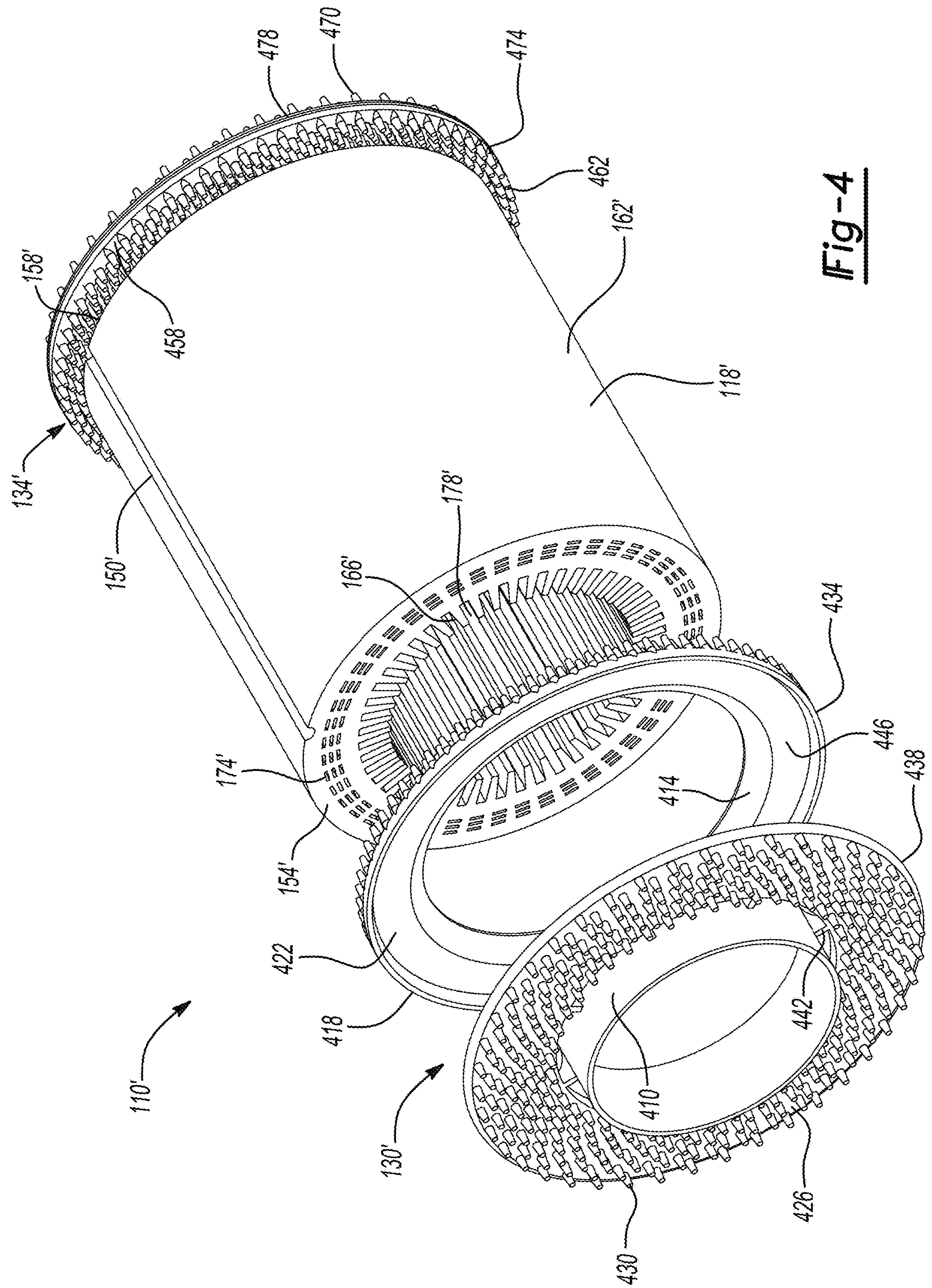
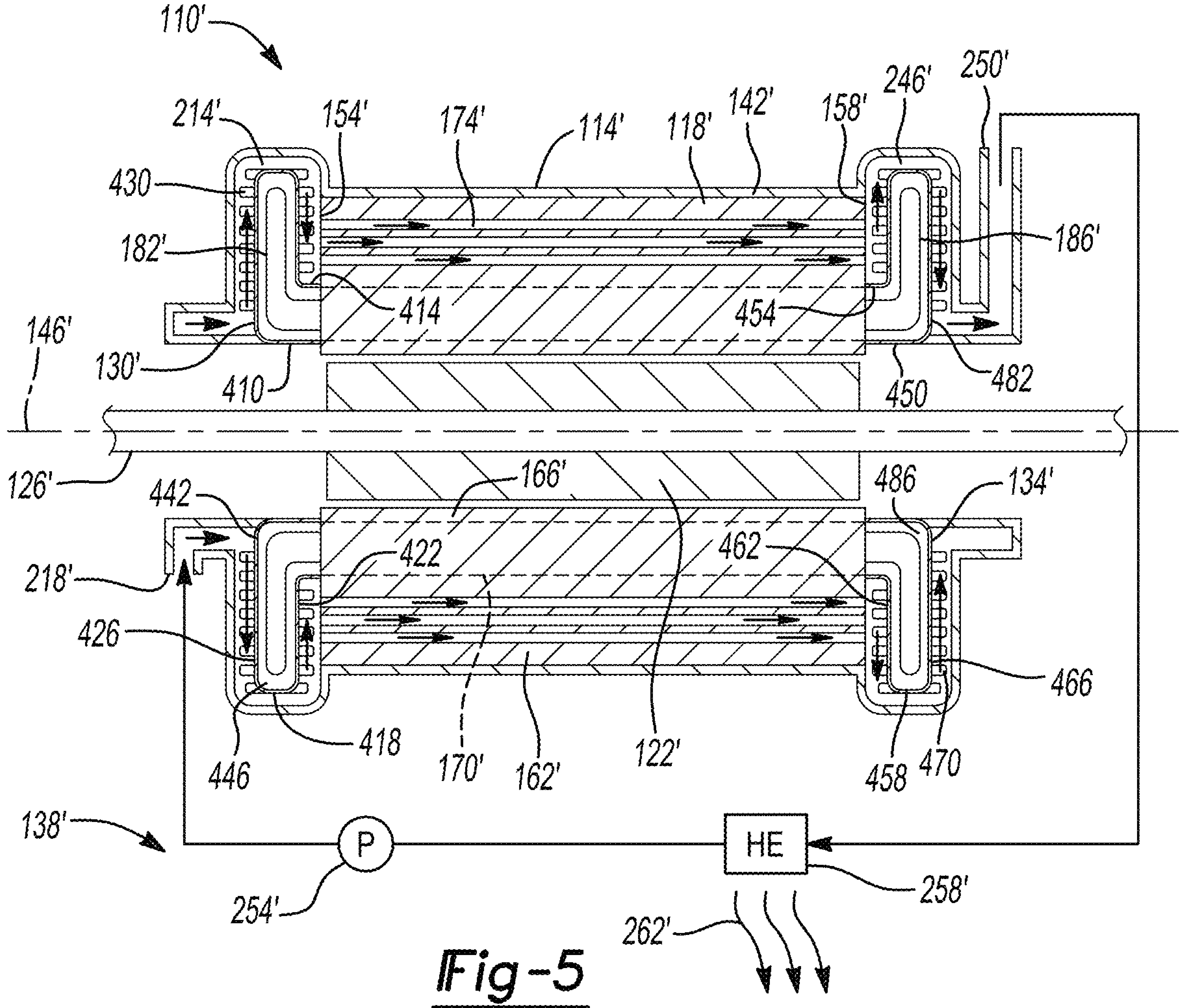

478
470
474
462
162'
158'
458
118'
134'
178'
150'
166'
434
446
438
174'
414
154'
422
442
418
410
110'
130'
426
430

Fig-4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214'
154'
174'
114'
118'
142'
158'
246'
250'
430
182'
186'
414
454
146'
130'
410
450
482
126'
442
166'
486
134'
422
462
218'
426
466
418
446
170'
162'
122'
458
470
138'
P
HE
254'
258'
262'

Fig-5

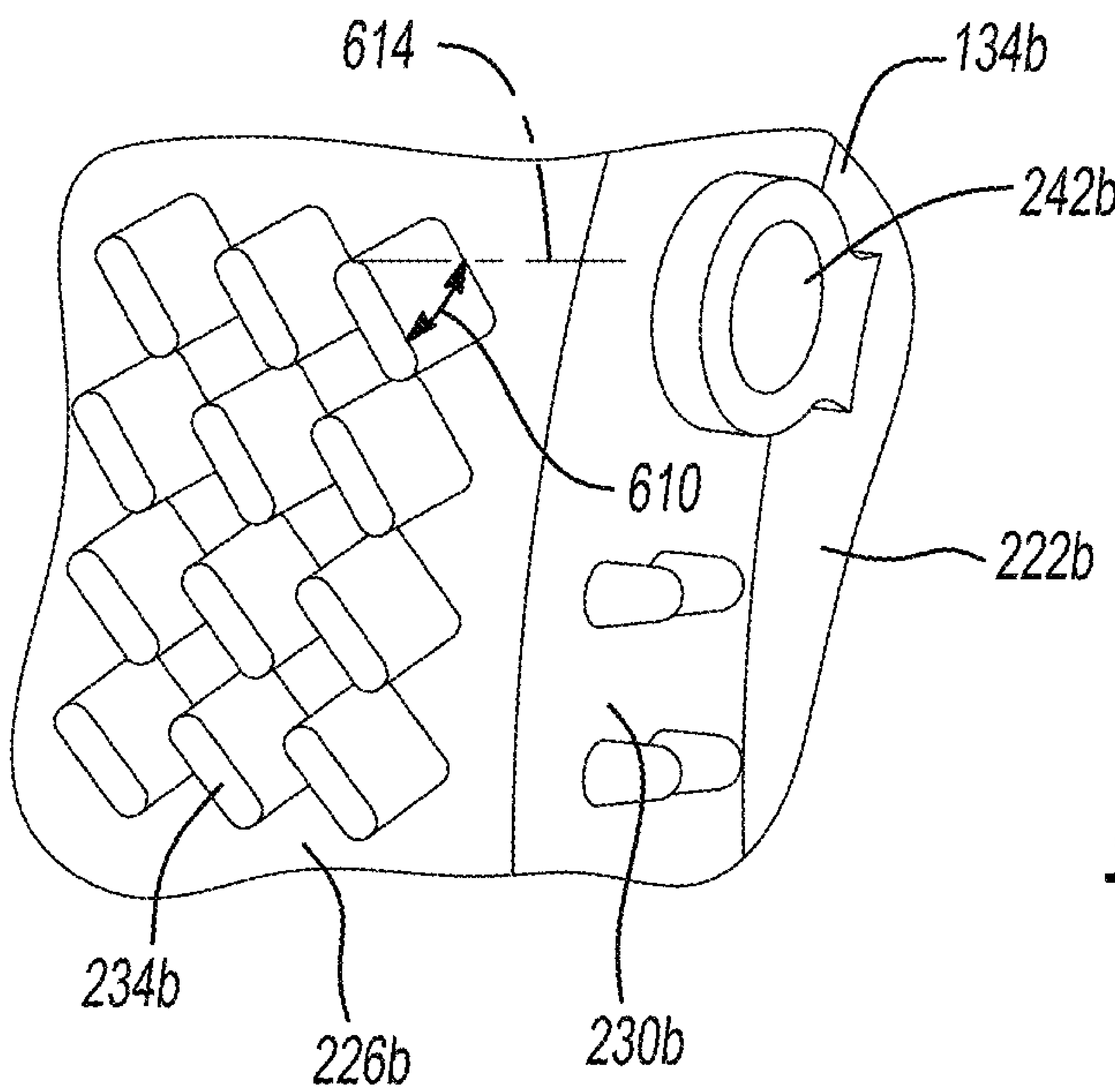
614
134b
242b
610
222b
234b
226b
230b

Fig-6

# ELECTRIC MOTOR AND STATOR COOLING APPARATUS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 17/128,281 filed Dec. 21, 2020, which is a continuation of U.S. application Ser. No. 15/820,934 filed Nov. 22, 2017 (now U.S. Pat. No. 10,879,749 issued Dec. 29, 2020). The disclosure of each of the above-referenced applications is incorporated by reference as if fully set forth in detail herein.

## FIELD

The present disclosure relates to an electric motor and a stator cooling apparatus for an electric motor.

## BACKGROUND

Electric motors, such as those used in vehicle drivelines, can generate heat during operation. Excess temperatures can have undesirable effects on performance and longevity of the electric motor and its associated components. As such, it can be advantageous to provide cooling to the motor to remove excess heat therefrom. While typical motor cooling methods can be sufficient for their intended uses, there continues to be a need for improved cooling of electric motors.

## SUMMARY

This section provides a general summary of the disclosure and is not a comprehensive disclosure of its full scope or all of its features.

In one form, the present disclosure provides an electric motor can include a stator body, a rotor, a plurality of electrically conductive windings, a first end cap, and a second end cap. The stator body can be disposed about an axis and can define a plurality of fluid channels. The fluid channels can extend axially through the stator body to provide fluid communication between a first axial end of the stator body and a second axial end of the stator body. The rotor can be disposed about the axis and rotatable relative to the stator body. The plurality of electrically conductive windings can form a plurality of first winding loops and a plurality of second winding loops. The first winding loops can extend axially outward from the first axial end of the stator body. The second winding loops can extend axially outward from the second axial end of the stator body. The first end cap can be coupled to the first axial end of the stator body. The first end cap can include a first wall and a plurality of first pins. The first wall can be disposed between the first winding loops and the fluid channels. The first pins can extend from a side of the first wall that is opposite the first winding loops. The second end cap can be coupled to the second axial end of the stator body. The second end cap can include a second wall and a plurality of second pins. The second wall can be disposed between the second winding loops and the fluid channels. The second pins can extend from a side of the second wall that is opposite the second winding loops.

According to a further embodiment, the electric motor can further include a housing disposed about the stator body. The housing can cooperate with the stator body and the first end cap to define a first chamber in fluid communication with the fluid channels. The first pins can extend into the first chamber. The housing can cooperate with the stator body and the second end cap to define a second chamber in fluid communication with the fluid channels. The second pins can extend into the second chamber.



According to a further embodiment, the electric motor can further include a pump including an inlet and outlet. The inlet of the pump can be in fluid communication with the second chamber to receive fluid therefrom. The outlet of the pump can be in fluid communication with the first chamber to pump fluid thereto.

According to a further embodiment, the electric motor can further include a at least one shroud that includes at least one of: a first shroud disposed about the axis between the first end cap and the housing and configured to guide fluid flow from the first chamber across the first pins to the fluid channels; or a second shroud disposed about the axis between the second end cap and the housing and configured to guide fluid flow from the fluid channels across the second pins to the second chamber.

According to a further embodiment, the first pins can extend radially outward from the first wall.

According to a further embodiment, the first pins can extend radially outward of a radially inward-most part of the fluid channels.

According to a further embodiment, the second pins can extend radially outward from the second wall.

According to a further embodiment, the second pins can extend radially outward of a radially inward-most part of the fluid channels.

According to a further embodiment, the electric motor can further include a sensor and at least one of the first end cap or the second end cap can define a sensor bore. The sensor can be removably disposed within the sensor bore and configured to output a signal that corresponds to a temperature of the electrically conducting windings.

According to a further embodiment, the first and second winding loops can be encased in a thermally conductive but electrically insulating resin that contacts the first and second walls and the first and second winding loops.

According to a further embodiment, the first and second winding loops can extend radially outward of a radially inward-most part of the fluid channels.

According to a further embodiment, the first wall can include a first annular body and a second annular body coupled to the first annular body to define a first winding cavity. The first winding loops can be disposed within the first winding cavity. The first pins can extend axially from at least one of: the first annular body in a direction toward the stator body, or the second annular body in a direction away from the stator body.

According to a further embodiment, the first pins can extend axially in the direction toward the stator body from the first annular body and axially in the direction away from the stator body from the second annular body.

According to a further embodiment, the second wall can include a third annular body and a fourth annular body coupled to the third annular body to define a second winding cavity. The second winding loops can be disposed within the second winding cavity. The second pins can extend axially from at least one of: the third annular body in a direction toward the stator body, or the second annular body in a direction away from the stator body.

According to a further embodiment, the second pins can extend axially in the direction toward the stator body from the third annular body and axially in the direction away from the stator body from the fourth annular body.

In another form, the present disclosure provides an electric motor including a housing, a stator body, a rotor, a plurality of electrically conductive windings, a first end cap, and a second end cap. The stator body can be disposed about an axis. The stator body can define a plurality of fluid channels that extend axially through the stator body to provide fluid communication between a first axial end of the stator body and a second axial end of the stator body. The rotor can be disposed about the axis and rotatable relative to the stator body. The plurality of electrically conductive windings can form a plurality of first winding loops and a plurality of second winding loops. The first winding loops can extend axially outward from the first axial end of the stator body. The second winding loops can extend axially outward from the second axial end of the stator body. The first end cap can be coupled to the first axial end of the stator body. The first end cap can include a first wall and a plurality of first pins. The first end cap and the housing can define a first fluid cavity in fluid communication with the fluid channels. The first end cap can define a first winding cavity separated from the first fluid cavity by the first wall. The first winding loops can be disposed within the first winding cavity. The first pins can extend from the first wall into the first fluid cavity. The second end cap can be coupled to the second axial end of the stator body. The second end cap can include a second wall and a plurality of second pins. The second end cap and the housing can define a second fluid cavity in fluid communication with the fluid channels. The second end cap can define a second winding cavity separated from the second fluid cavity by the second wall. The second winding loops can be disposed within the second winding cavity. The second pins can extend from the second wall into the second fluid cavity.

According to a further embodiment, the first pins can extend radially outward from the first wall and the second pins can extend radially outward from the second wall.

According to a further embodiment, the first and second pins can extend radially outward of a radially inward-most part of the fluid channels.

According to a further embodiment, the first and second winding loops can be encased in a thermally conductive but electrically insulating resin that contacts the first and second walls and the first and second winding loops.

According to a further embodiment, the first and second winding loops can extend radially outward of a radially inward-most part of the fluid channels.

According to a further embodiment, the first wall can include a first annular body and a second annular body coupled to the first annular body to define the first winding cavity. The first pins can extend axially from at least one of: the first annular body in a direction toward the stator body, or the second annular body in a direction away from the stator body. The second wall can include a third annular body and a fourth annular body coupled to the third annular body to define the second winding cavity. The second pins can extend axially from at least one of: the third annular body in a direction toward the stator body, or the second annular body in a direction away from the stator body.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

## DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations and are not intended to limit the scope of the present disclosure.

FIG. **1** is a perspective view of a portion of an electric motor of a first construction, constructed in accordance with the teachings of the present disclosure;

FIG. **2** is a sectional view of a stator core of the electric motor of FIG. **1**;

FIG. **3** is a schematic sectional view of a portion of the electric motor of FIG. **1**, schematically illustrating a cooling circuit for cooling the electric motor;

FIG. **4** is a perspective view of a portion of an electric motor of a second construction, constructed in accordance with the teachings of the present disclosure;

FIG. **5** is a schematic sectional view of a portion of the electric motor of FIG. **4**, schematically illustrating a cooling circuit for cooling the electric motor; and

FIG. **6** is a perspective view of a portion of an electric motor of a third construction.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

## DETAILED DESCRIPTION

With reference to FIGS. **1**-**3**, an electric motor **110** of a first construction is illustrated. The electric motor **110** can include a housing **114**, a stator **118**, a rotor **122**, an output shaft **126**, a first end cap **130**, a first shroud **132**, a second end cap **134**, a second shroud **136**, and a cooling system **138**. In the example provided, the housing **114** can define a generally cylindrical cavity **142** disposed about an axis **146**. The stator **118** can be disposed about the axis **146** within the cylindrical cavity **142** and can be fixedly coupled to the housing **114** such that the stator **118** is non-rotatable relative to the housing **114**. In the example provided, an outermost cylindrical surface of the stator **118** can include one or more grooves **150** that can extend axially along the stator **118** and can mate with a spline (not specifically shown) on an interior surface of the housing **114**, though other configurations can be used. The stator **118** can be formed of a plurality of stator laminations stacked axially end to end along the axis **146**, though other configurations can be used.

The stator **118** can be generally annular in shape, with a first axial face or end **154** and a second axial face or end **158** opposite the first axial end **154**. The stator **118** can include an annular body **162**, a plurality of winding poles **166**, and a plurality of wire windings **170**. The annular body **162** can be fixedly coupled to the winding poles **166** to make up the stator core. The annular body **162** can define a plurality of fluid channels **174** that can be open at the first axial end **154** and the second axial end **158** and can extend axially therebetween to permit fluid communication between the first axial end **154** and the second axial end **158**. The fluid channels **174** can be disposed about the axis **146**. In the example provided, the fluid channels **174** are equally spaced apart in the circumferential direction about the axis **146**.

The winding poles **166** can extend radially inward from the radially inward side of the annular body **162**. The winding poles **166** can be equally spaced apart in the circumferential direction about the axis **146** to define winding slots **178** between adjacent ones of the winding poles **166**. Thus, the winding poles **166** and winding slots **178** can be radially inward of the fluid channels **174**. Electrically conductive wire can extend through the winding slots **178** and be wound about the winding poles **166** to form the wire windings **170** in a manner such that a first section of the wire windings **170** forms first winding loops **182** that extend axially outward from the first axial end **154** of the stator **118** and a second section of the wire windings **170** forms second winding loops **186** that extend axially outward from the second axial end **158** of the stator **118**.

The rotor **122** can be disposed about the axis **146** and can be supported for rotation relative to the stator **118**. The stator **118** can be disposed about the rotor **122** such that the rotor **122** is radially inward of the winding poles **166**. The output shaft **126** can be disposed about the axis **146** and fixedly coupled to the rotor **122** for common rotation about the axis **146**. In the example provided, the output shaft **126** can extend axially from both axial ends of the rotor **122**. While not specifically shown, the output shaft **126** can be coupled to a driveline of a vehicle for providing torque to a set of vehicle wheels.

The first end cap **130** can be a generally annular body and can include a first inner wall **190**, a first outer wall **194**, a first end wall **198**, and a plurality of first fins or pins **202**. In the example provided, the first end cap **130** is unitarily formed from a thermally conductive, but electrically insulating material, such as by injection molding of a plastic for example. A proximal end of the first inner wall **190** can abut the first axial end **154** of the stator **118**. The first inner wall **190** can extend axially from the first axial end **154** of the stator **118** to a distal end of the first inner wall **190**. The first inner wall **190** can be coaxial with the axis **146**. An outward facing cylindrical side of the first inner wall **190** can be disposed radially inward of the first winding loops **182** and an inward facing cylindrical side of the first inner wall **190** can be radially outward of the rotor **122**.

The first inner wall **190** can define a pocket **200** configured to receive a temperature sensor **204**. In the example provided, the pocket **200** extends generally axially relative to the axis **146** and is open facing axially away from the first axial end **154**. The pocket **200** can be radially inward of the first winding loops **182** and can extend axially toward the first axial end **154** such that the temperature sensor **204** therein can be in close proximity to the first winding loops **182**. For example, the temperature sensor **204** can axially overlap with the first winding loops **182**. In the example provided, the temperature sensor **204** is a thermistor, though other types of sensors can be used. Thus, pocket **200** and temperature sensor **204** can be located at a back (e.g., radially inner) plane of the first winding loops **182** such that they are away from the cooling flow, but in strong thermal conduction with the first winding loops **182** to provide accurate temperature readings of the first winding loops **182**. The temperature sensor **204** can be removably coupled to the pocket **200**, such as being threaded into the pocket **200** for example.

A proximal end of the first outer wall **194** can abut the first axial end **154** of the stator **118**. The first outer wall **194** can extend axially from the first axial end **154** of the stator **118** to a distal end of the first outer wall **194**. The first outer wall **194** can be coaxial with the axis **146**. In the example provided, the first outer wall **194** can be generally parallel to the first inner wall **190**. An outward facing cylindrical side of the first outer wall **194** can be disposed radially inward of the fluid channels **174** and an inward facing cylindrical side of the first outer wall **194** can be disposed radially outward of the first winding loops **182**.

The first end wall **198** can extend generally radially between the distal end of the first outer wall **194** and the first inner wall **190**. In the example provided, the first end wall **198** connects the distal end of the first outer wall **194** to the first inner wall **190** at a location on the first inner wall **190** that is axially between the proximal and distal ends of the first inner wall **190**. In the example provided, the first end wall **198** can be generally perpendicular to the axis **146**, though other configurations can be used. The first inner wall **190**, the first outer wall **194**, and the first end wall **198** can cooperate to define a first winding cavity **206** that is disposed annularly about the axis **146** and open toward the stator **118** and configured to receive the first winding loops **182** therein. As such, the first winding cavity **206** can be open to the slots **178** of the stator **118**. In the example provided, the first end wall **198** can include one or more first ports **210** that can be open axially through the first end wall **198**.

A proximal end of each first pin **202** can be fixedly coupled to the first outer wall **194** and each first pin **202** can extend radially outward from the first outer wall **194** to a distal end. In the example provided, the distal ends of the first pins **202** can be radially outward of a radially innermost part of the openings of the fluid channels **174**. In the example provided, the first pins **202** can be equally spaced in the circumferential direction about the first outer wall **194**, though other configurations can be used. In the example provided, the first outer wall **194** includes six equally spaced rows of the first pins **202** in the axial direction, though more or fewer rows can be used, or the first pins can be such that they are not arranged in ordered rows. In the example provided, some of the first pins **202** also extend axially outward (i.e., the direction away from the stator **118**) from the first end wall **198**. In the example provided, the first pins **202** are generally cylindrical or conical in shape, but other configurations can be used, such as fins, ribs, blades, tabs, or pyramid-shapes for example.

The first axial end **154** of the stator **118**, the inner surface of the housing **114**, and the first outer wall **194** can cooperate to define a first chamber or fluid cavity **214** in fluid communication with the fluid channels **174**. In the example provided, the first chamber **214** is also defined by the first end wall **198** and the portion of the first inner wall **190** that is axially outward of the first end wall **198**, though other configurations can be used. Thus, the first pins **202** can extend within the first chamber **214**. In the example provided, the housing **114** defines an inlet port **218** in fluid communication with the first chamber **214**.

The first shroud **132** can be a hollow, generally cylindrical body disposed about the axis **146** and open at both axial ends of the first shroud **132**. The first shroud **132** can be fixedly coupled to the stator **118** or the housing **114**. The first shroud **132** can be generally between the first end cap **130** and the housing **114** to divide the first chamber **214** into an outer region and an inner region. The inner region can be open to the fluid channels **174**, i.e., in direct fluid communication with the fluid channels **174**. In other words, fluid flowing from the outer region to the fluid channels **174** must pass through the inner region. A radially inward surface of the first shroud **132** can be in close proximity to the distal ends of the first pins **202** such that fluid flowing through the inner region to the fluid channels **174** is guided across the first pins **202** and maintains a high velocity while passing between the first pins **202**.

The second end cap **134** can be similar to the first end cap **130** except as otherwise shown or described herein. The second end cap **134** can be a generally annular body and can include a second inner wall **222**, a second outer wall **226**, a second end wall **230**, and a plurality of second fins or pins **234**. In the example provided, the second end cap **134** is unitarily formed from a thermally conductive, but electrically insulating material, such as by injection molding of a plastic for example. A proximal end of the second inner wall **222** can abut the second axial end **158** of the stator **118**. The second inner wall **222** can extend axially from the second axial end **158** of the stator **118** to a distal end of the second inner wall **222**. The second inner wall **222** can be coaxial with the axis **146**. An outward facing cylindrical side of the second inner wall **222** can be disposed radially inward of the second winding loops **186** and an inward facing cylindrical side of the second inner wall **222** can be radially outward of the rotor **122**.

The second inner wall **222** can optionally define a second pocket **232** configured to receive a second temperature sensor **236**. The second pocket **232** and second temperature sensor **236** can be similar to the pocket **200** and temperature sensor **204** except as otherwise shown or described herein. In the example provided, the second pocket **232** extends generally axially relative to the axis **146** and is open facing axially away from the second axial end **158**. The second pocket **232** can be radially inward of the second winding loops **186** and can extend axially toward the second axial end **158** such that the second temperature sensor **236** therein can be in close proximity to the second winding loops **186**. For example, the second temperature sensor **236** can axially overlap with the second winding loops **186**. In the example provided, the second temperature sensor **236** is a thermistor, though other types of sensors can be used. Thus, second pocket **232** and second temperature sensor **236** can be located at a back (e.g., radially inner) plane of the second winding loops **186** such that they are away from the cooling flow, but in strong thermal conduction with the second winding loops **186** to provide accurate temperature readings of the second winding loops **186**. The second temperature sensor **236** can be removably coupled to the second pocket **232**, such as being threaded into the second pocket **232** for example.

A proximal end of the second outer wall **226** can abut the second axial end **158** of the stator **118**. The second outer wall **226** can extend axially from the second axial end **158** of the stator **118** to a distal end of the second outer wall **226**. The second outer wall **226** can be coaxial with the axis **146**. In the example provided, the second outer wall **226** can be generally parallel to the second inner wall **222**. An outward facing cylindrical side of the second outer wall **226** can be disposed radially inward of the fluid channels **174** and an inward facing cylindrical side of the second outer wall **226** can be disposed radially outward of the second winding loops **186**.

The second end wall **230** can extend generally radially between the distal end of the second outer wall **226** and the second inner wall **222**. In the example provided, the second end wall **230** connects the distal end of the second outer wall **226** to the second inner wall **222** at a location on the second inner wall **222** that is axially between the proximal and distal ends of the second inner wall **222**. In the example provided, the second end wall **230** can be generally perpendicular to the axis **146**, though other configurations can be used. The second inner wall **222**, the second outer wall **226**, and the second end wall **230** can cooperate to define a second winding cavity **238** that is disposed annularly about the axis **146** and open toward the stator **118** and configured to receive the second winding loops **186** therein. As such, the second winding cavity **238** can be open to the slots **178** of the stator **118**. In the example provided, the second end wall **230** can include one or more second ports **242** that can be open axially through the second end wall **230**.

A proximal end of each second pin **234** can be fixedly coupled to the second outer wall **226** and each second pin **234** can extend radially outward from the second outer wall **226** to a distal end. In the example provided, the distal ends of the second pins **234** can be radially outward of a radially innermost part of the openings of the fluid channels **174**. In the example provided, the second pins **234** can be equally spaced in the circumferential direction about the second outer wall **226**, though other configurations can be used. In the example provided, the second outer wall **226** includes six equally spaced rows of the second pins **234** in the axial direction, though more or fewer rows can be used, or the second pins can be such that they are not arranged in ordered rows. In the example provided, some of the second pins **234** also extend axially outward (i.e., the direction away from the stator **118**) from the second end wall **230**. In the example provided, the second pins **234** are generally cylindrical or conical in shape, but other configurations can be used, such as fins, ribs, blades, tabs, or pyramid-shapes for example.

With additional reference to FIG. **6**, a portion of a second end cap **134*b*** is illustrated with one example of such a different configuration of the second pins **234*b***. The second end cap **134*b*** and second pins **234*b*** can be similar to the second pins **234** (FIGS. **1** and **3**), except as otherwise shown or described herein. Elements of the second end cap **134*b*** that are similar to elements of the second end cap **134** (FIGS. **1** and **3**) are indicated with similar reference numerals followed by the numeral 'b' and only differences are described in detail herein. In the example shown, the second pins **234*b*** have a fin, rib, or blade type shape that are angled to promote uniform rotational flow around the second outer wall **226*b***. In the example provided, the second pins **234*b*** can extend longitudinally at an angle **610** relative to the axis **146** (e.g., relative to line **614** which is parallel to the axis **146** shown in FIG. **3**). This rotational flow around the second outer wall **226*b*** can promote uniform flow to the outlet port **250** (FIG. **3**) and can increase heat absorption by the fluid. In the example provided, only the second pins **234*b*** have the angled, fin/rib/blade type of pin. In an alternative configuration, not specifically shown, the first end cap **130** (FIGS. **1** and **3**) and not the second end cap **134** (FIGS. **1** and **3**) can have such angled pins to promote rotational flow. In another alternative configuration, not specifically shown, both the first end cap **130** (FIGS. **1** and **3**) and the second end cap **134*b*** can have such angled pins to promote rotational flow.

Returning to the example shown in FIGS. **1-3**, the second axial end **158** of the stator **118**, the inner surface of the housing **114**, and the second outer wall **226** can cooperate to define a second chamber or fluid cavity **246** in fluid communication with the fluid channels **174**. In the example provided, the second chamber **246** is also defined by the second end wall **230** and the portion of the second inner wall **222** that is axially outward of the second end wall **230**, though other configurations can be used. Thus, the second pins **234** can extend within the second chamber **246**. In the example provided, the housing **114** defines an outlet port **250** in fluid communication with the second chamber **246**.

The second shroud **136** can be similar to the first shroud **132**, except as otherwise shown or described herein. The second shroud **136** can be a hollow, generally cylindrical body disposed about the axis **146** and open at both axial ends of the second shroud **136**. The second shroud **136** can be fixedly coupled to the stator **118** or the housing **114**. The second shroud **136** can be generally between the second end cap **230** and the housing **114** to divide the second chamber **246** into an outer region and an inner region. The inner region can be open to the fluid channels **174**, i.e., in direct fluid communication with the fluid channels **174**. In other words, fluid flowing from the fluid channels **174** to the outer region must pass through the inner region. A radially inward surface of the second shroud **136** can be in close proximity to the distal ends of the second pins **234** such that fluid flowing through the inner region from the fluid channels **174** is guided across the second pins **234** and maintains a high velocity while passing between the second pins **234**.

During assembly of the motor **110**, the first end cap **130** can be fixedly mounted to the first axial end **154** of the stator **118** and the second end cap **134** can be fixedly mounted to the second axial end **158** of the stator **118**. The slots **178**, the first winding cavity **206**, and the second winding cavity **238** can then be filled with a thermally conductive, but electrically insulating resin. For example, the resin may be pumped into the first winding cavity **206** via the first ports **210** until the resin fills the first winding cavity **206**, the slots **178**, and the second winding cavity **238**. The resin may then be allowed to harden such that the hardened resin encapsulates the first winding loops **182** and the second winding loops **186**, and also contacts the first end cap **130** and the second end cap **134**.

Alternatively, the motor **110** may be positioned such that the axis **146** extends in a vertical direction relative to the ground and the first axial end **154** is facing upwards. In this vertical position of the motor **110**, the second ports **242** can be sealed and resin may be poured in from the top through the first ports **210** until the resin fills the second winding cavity **238**, the slots **178**, and the first winding cavity **206**. Alternatively, the second ports **242** can be open such that the resin can be pumped in from the bottom through the second ports **242** until the resin fills the second winding cavity **238**, the slots **178**, and the first winding cavity **206**.

The cooling system **138** can include a pump **254** and a heat exchanger **258**. The pump **254** can have an outlet coupled to the inlet port **218** for fluid communication therewith such that the pump **254** can pump fluid (e.g., dielectric cooling fluid) to the inlet port **218**. The pump **254** can have an inlet coupled to an outlet of the heat exchanger **258** for fluid communication therewith to receive fluid from the heat exchanger **258**. The heat exchanger **258** can be any suitable type of heat exchanger configured to release heat **262** to a heat sink (e.g., the atmosphere). The inlet of the heat exchanger **258** can be coupled to the outlet port **250** of the housing **114** to receive fluid therefrom. In an alternative configuration, not specifically shown, the heat exchanger **258** can be in-line between the pump **254** and the inlet port **218** (e.g., the inlet of the heat exchanger **258** can be coupled to the outlet of the pump **254**, the outlet of the heat exchanger **258** can be coupled to the inlet port **218**, and the inlet of the pump **254** can be coupled to the outlet port **250**).

Thus, in operation, the pump **254** can pump cooling fluid through the cooling circuit, such that the fluid flows from the inlet port **218**, axially across the first end cap **130** and between the first pins **202** to absorb heat from the first winding loops **182** via the first pins **202**. The fluid can then flow into and through the fluid channels **174** to absorb more heat from the stator **118**. The fluid can then flow from the fluid channels **174** axially across the second end cap **134** and between the second pins **234** to absorb heat from the second winding loops **186** via the second pins **234**. The fluid can then flow through the outlet port **250** to the heat exchanger, where the heat **262** can be transferred from the fluid to a heat sink (e.g., the atmosphere).

With additional reference to FIGS. **4-5**, an electric motor **110'** of a second construction is illustrated. The electric motor **110'** can be similar to the electric motor **110** of FIGS. **1-3** except as otherwise shown or described herein. Elements shown or described herein with primed reference numerals can be similar to those shown and described above with reference to similar non-primed reference numerals except as otherwise shown or described herein. Accordingly, only differences will be described in detail herein. The electric motor **110'** can include a housing **114'**, a stator **118'**, a rotor **122'**, an output shaft **126'**, a first end cap **130'**, a second end cap **134'** and a cooling system **138'**. In the example provided, the housing **114'** can define a generally cylindrical cavity **142'** disposed about an axis **146'**. The stator **118'** can be disposed about the axis **146'** within the cylindrical cavity **142'** and can be fixedly coupled to the housing **114'** such that the stator **118'** is non-rotatable relative to the housing **114'**. In the example provided, an outermost cylindrical surface of the stator **118'** can include one or more grooves **150'** that can extend axially along the stator **118'** and can mate with a spline (not specifically shown) on an interior surface of the housing **114'**, though other configurations can be used. The stator **118'** can be formed of a plurality of stator laminations stacked axially end to end along the axis **146'**, though other configurations can be used.



The stator **118'** can be generally annular in shape, with a first axial end **154'** and a second axial end **158'** opposite the first axial end **154'**. The stator **118'** can include an annular body **162'**, a plurality of winding poles **166'**, and a plurality of wire windings **170'**. The annular body **162'** can define a plurality of fluid channels **174'** that can be open at the first axial end **154'** and the second axial end **158'** and can extend axially therebetween to permit fluid communication between the first axial end **154'** and the second axial end **158'**. The fluid channels **174'** can be disposed about the axis **146'**. In the example provided, the fluid channels **174'** are equally spaced apart in the circumferential direction about the axis **146'**.

The winding poles **166'** can extend radially inward from the radially inward side of the annular body **162'**. The winding poles **166'** can be equally spaced apart in the circumferential direction about the axis **146'** to define winding slots **178'** between adjacent ones of the winding poles **166'**. Thus, the winding poles **166'** and winding slots **178'** can be radially inward of the fluid channels **174'**. Electrically conductive wire can extend through the winding slots **178'** and be wound about the winding poles **166'** to form the wire windings **170'** in a manner such that a first section of the wire windings **170'** forms first winding loops **182'** that are axially outward from the first axial end **154'** of the stator **118'** and a second section of the wire windings **170'** forms second winding loops **186'** that are axially outward from the second axial end **158'** of the stator **118'**.

The first winding loops **182'** can have a bend such that the first winding loops **182'** have a first portion that is proximate to the stator **118'** and extends axially outward therefrom, and a second portion that extends radially outward from the first portion. The second portion of the first winding loops **182'** can extend radially outward of a radially inward-most part of the fluid channels **174'**. In the example provided, the second portion of the first winding loops **182'** extends radially outward of a radially outward-most part of the fluid channels **174'**.

The second winding loops **186'** can have a bend such that the second winding loops **186'** have a first portion that is proximate to the stator **118'** and extends axially outward therefrom, and a second portion that extends radially outward from the first portion. The second portion of the second winding loops **186'** can extend radially outward of a radially inward-most part of the fluid channels **174'**. In the example provided, the second portion of the second winding loops **186'** extends radially outward of a radially outward-most part of the fluid channels **174'**.

The rotor **122'** can be disposed about the axis **146'** and can be supported for rotation relative to the stator **118'**. The stator **118'** can be disposed about the rotor **122'** such that the rotor **122'** is radially inward of the winding poles **166'**. The output shaft **126'** can be disposed about the axis **146'** and fixedly coupled to the rotor **122'** for common rotation about the axis **146'**. In the example provided, the output shaft **126'** can extend axially from both axial ends of the rotor **122'**. While not specifically shown, the output shaft **126'** can be coupled to a driveline of a vehicle for providing torque to a set of vehicle wheels.

The first end cap **130'** can be a generally annular body and can include a first inner wall **410**, a pair of first outer walls **414**, **418**, a pair of first end walls **422**, **426**, and a plurality of first fins or pins **430**. In the example provided, the first end cap **130'** is constructed of a unitarily formed first body **434** and a separate, unitarily formed second body **438** that is fixedly coupled to the first body **434** such as by plastic welding for example. The first and second bodies **434**, **438** of the first end cap **130'** can be formed by any suitable means, such as by injection molding of a plastic for example. The first end cap **130'** can be formed from a thermally conductive, but electrically insulating material.

A proximal end of the first inner wall **410** can abut the first axial end **154'** of the stator **118'**. The first inner wall **410** can extend generally axially from the first axial end **154'** of the stator **118'** to a distal end of the first inner wall **410**. The first inner wall **410** can be coaxial with the axis **146'**, radially inward of the first winding loops **182'** and radially outward of the rotor **122'**. A proximal end of the first outer wall **414** can abut the first axial end **154'** of the stator **118'**. The first outer wall **414** can extend generally axially from the first axial end **154'** of the stator **118'** to a distal end of the first outer wall **414**. The first outer wall **414** can be coaxial with the axis **146'**, radially outward of the first winding loops **182'** and the slots **178'**, and radially inward of the fluid channels **174'**. The distal end of the first outer wall **414** can be axially between the stator **118'** and the distal end of the first inner wall **410**.

The first end wall **422** can be annular in shape and can extend radially outward from the distal end of the first outer wall **414**. In the example provided, the first end wall **422** can extend radially outward of the radially outward-most part of the fluid channels **174'** and can extend radially outward of the radially outward-most cylindrical surface of the stator **118'**. The first end wall **426** can be annular in shape and can extend radially outward from the first inner wall **410**. In the example provided, the first end wall **426** is axially between the first end wall **422** and the distal end of the first inner wall **410** such that the first inner wall **410** extends axially outward of the first end wall **426**. In the example provided, the first end wall **426** has an inner diameter that is greater than that of the first inner wall **410** and is fixedly coupled to the first inner wall **410** by a plurality of spokes **442** spaced circumferentially about the axis **146'** and extending between the first inner wall **410** and the first end wall **426**. The first end wall **426** can extend radially outward of the radially outward-most part of the fluid channels **174'** and can extend radially outward of the radially outward-most cylindrical surface of the stator **118'**. The first outer wall **418** can extend axially between the radially outward-most parts of the first end walls **422**, **426**. Accordingly, the first end walls **422**, **426**, the first inner wall **410**, and the first outer walls **414**, **418** can cooperate to define a first winding cavity **446** that is disposed annularly about the axis **146'** and open toward the stator **118'** and configured to receive the first winding loops **182'** therein. As such, the first winding cavity **446** can be open to the slots **178'** of the stator **118'**.

A proximal end of each first pin **430** can be fixedly coupled to the first end wall **422** or the first end wall **426**. Each first pin **430** coupled to the first end wall **422** can extend axially inward (i.e., toward the stator **118'**) from the first end wall **422** to a distal end. Each first pin **430** coupled to the first end wall **426** can extend axially outward (i.e., away from the stator **118'**) from the first end wall **426** to a distal end. In the example provided, the first pins **430** can be spaced apart to permit fluid to flow between the first pins **430**. Thus, the first end cap **130'** can have pins extending axially toward and away from the stator **118'**. In the example provided, the first pins **430** are generally cylindrical or conical in shape, but other configurations can be used, such as fins, ribs, blades, tabs, or pyramid-shapes for example.

The first axial end **154'** of the stator **118'**, the inner surface of the housing **114'**, the first outer walls **414**, **418**, and the first end walls **422**, **426** can cooperate to define a first chamber or fluid cavity **214'** in fluid communication with the fluid channels **174'**. In the example provided, the first chamber **214'** is also defined by the portion of the first inner wall **410** that is axially outward of the first end wall **426**, though other configurations can be used. Thus, the first pins **430** can extend within the first chamber **214'**. In the example provided, the housing **114'** defines an inlet port **218'** in fluid communication with the first chamber **214'**.

The second end cap **134'** can be similar to the first end cap **130'** except as otherwise shown or described herein. The second end cap **134'** can be a generally annular body and can include a second inner wall **450**, a pair of second outer walls **454**, **458**, a pair of second end walls **462**, **466**, and a plurality of second fins or pins **470**. In the example provided, the second end cap **134'** is constructed of a unitarily formed third body **474** and a separate, unitarily formed fourth body **478** that is fixedly coupled to the third body **474** such as by plastic welding for example. The third and fourth bodies **474**, **478** of the second end cap **134'** can be formed by any suitable means, such as by injection molding of a plastic for example. The second end cap **134'** can be formed from a thermally conductive, but electrically insulating material.

A proximal end of the second inner wall **450** can abut the second axial end **158'** of the stator **118'**. The second inner wall **450** can extend generally axially from the second axial end **158'** of the stator **118'** to a distal end of the second inner wall **450**. The second inner wall **450** can be coaxial with the axis **146'**, radially inward of the second winding loops **186'** and radially outward of the rotor **122'**. A proximal end of the second outer wall **454** can abut the second axial end **158'** of the stator **118'**. The second outer wall **454** can extend generally axially from the second axial end **158'** of the stator **118'** to a distal end of the second outer wall **454**. The second outer walls **454** can be coaxial with the axis **146'**, radially outward of the second winding loops **186'** and the slots **178'**, and radially inward of the fluid channels **174'**. The distal end of the second outer wall **454** can be axially between the stator **118'** and the distal end of the second inner wall **450**.

The second end wall **462** can be annular in shape and can extend radially outward from the distal end of the second outer wall **454**. In the example provided, the second end wall **462** can extend radially outward of the radially outward-most part of the fluid channels **174'** and can extend radially outward of the radially outward-most cylindrical surface of the stator **118'**. The second end wall **466** can be annular in shape and can extend radially outward from the second inner wall **450**. In the example provided, the second end wall **466** is axially between the second end wall **462** and the distal end of the second inner wall **450** such that the second inner wall **450** extends axially outward of the second end wall **466**. In the example provided, the second end wall **466** has an inner diameter that is greater than that of the second inner wall **450** and is fixedly coupled to the second inner wall **450** by a plurality of spokes **482** spaced circumferentially about the axis **146'** and extending between the second inner wall **450** and the second end wall **466**. The second end wall **466** can extend radially outward of the radially outward-most part of the fluid channels **174'** and can extend radially outward of the radially outward-most cylindrical surface of the stator **118'**. The second outer wall **458** can extend axially between the radially outward-most parts of the second end walls **462**, **466**. Accordingly, the second end walls **462**, **466**, the second inner wall **450**, and the second outer walls **454**, **458** can cooperate to define a second winding cavity **486** that is disposed annularly about the axis **146'** and open toward the stator **118'** and configured to receive the second winding loops **186'** therein. As such, the second winding cavity **486** can be open to the slots **178'** of the stator **118'**.

A proximal end of each second pin **470** can be fixedly coupled to the second end wall **462** or the second end wall **466**. Each second pin **470** coupled to the second end wall **462** can extend axially inward (i.e., toward the stator **118'**) from the second end wall **462** to a distal end. Each second pin **470** coupled to the second end wall **466** can extend axially outward (i.e., away from the stator **118'**) from the second end wall **466** to a distal end. In the example provided, the second pins **470** can be spaced apart to permit fluid to flow between the second pins **470**. Thus, the second end cap **134'** can have pins extending axially toward and away from the stator **118'**. In the example provided, the second pins **470** are generally cylindrical or conical in shape, but other configurations can be used, such as fins, ribs, blades, tabs, or pyramid-shapes for example.

While not specifically shown, the first pins **430**, and/or the second pins **470** can be constructed to promote uniform rotational flow of the fluid around the first and/or second end cap **130'**, **134'**, such as being fin, rib, or blade shaped and disposed at prescribed angles similar to those shown in FIG. **6**.

Returning to the example provided in FIGS. **4** and **5**, the second axial end **158'** of the stator **118'**, the inner surface of the housing **114'**, the second outer walls **454**, **458**, and the second end walls **462**, **466** can cooperate to define a second chamber or fluid cavity **246'** in fluid communication with the fluid channels **174'**. In the example provided, the second chamber **246'** is also defined by the portion of the second inner wall **450** that is axially outward of the second end wall **466**, though other configurations can be used. Thus, the second pins **470** can extend within the second chamber **246'**. In the example provided, the housing **114'** defines an outlet port **250'** in fluid communication with the second chamber **246'**.

During assembly of the motor **110'**, the first end cap **130'** can be fixedly mounted to the first axial end **154'** of the stator **118'** and the second end cap **134'** can be fixedly mounted to the second axial end **158'** of the stator **118'**. The slots **178'**, the first winding cavity **446**, and the second winding cavity **486** can then be filled with a thermally conductive, but electrically insulating resin. For example, the resin may be pumped into the first winding cavity **446** via the gaps between the spokes **442** until the resin fills the first winding cavity **446**, the slots **178'**, and the second winding cavity **486**. The resin may then be allowed to harden such that the hardened resin encapsulates the first winding loops **182'** and the second winding loops **186'**, and also contacts the first end cap **130'** and the second end cap **134'**.

Alternatively, the motor **110'** may be positioned such that the axis **146'** extends in a vertical direction relative to the ground and the first axial end **154'** is facing upwards. In this vertical position of the motor **110'**, the gaps between the spokes **482** can be sealed and resin may be poured in from the top through the gaps between the spokes **442** until the resin fills the second winding cavity **486**, the slots **178'**, and the first winding cavity **446**. Alternatively, the gaps between the spokes **482** can be open such that the resin can be pumped in from the bottom through the gaps between the spokes **482** until the resin fills the second winding cavity **486**, the slots **178'**, and the first winding cavity **446**.

The cooling system **138'** can include a pump **254'** and a heat exchanger **258'**. The pump **254'** can have an outlet coupled to the inlet port **218'** for fluid communication therewith such that the pump **254'** can pump fluid (e.g., dielectric cooling fluid) to the inlet port **218'**. The pump **254'** can have an inlet coupled to an outlet of the heat exchanger **258'** for fluid communication therewith to receive fluid from the heat exchanger **258'**. The heat exchanger **258'** can be any suitable type of heat exchanger configured to release heat **262'** to a heat sink (e.g., the atmosphere). The inlet of the heat exchanger **258'** can be coupled to the outlet port **250'** of the housing **114'** to receive fluid therefrom. In an alternative configuration, not specifically shown, the heat exchanger **258'** can be in-line between the pump **254'** and the inlet port **218'** (e.g., the inlet of the heat exchanger **258'** can be coupled to the outlet of the pump **254'**, the outlet of the heat exchanger **258'** can be coupled to the inlet port **218'**, and the inlet of the pump **254'** can be coupled to the outlet port **250'**).

Thus, in operation, the pump **254'** can pump cooling fluid through the cooling circuit, such that the fluid flows from the inlet port **218'**, radially outward across the first end wall **426** and between the first pins **430** thereon to absorb heat from the first winding loops **182** via the first pins **430**. The fluid can then flow axially around the first outer wall **418** and radially inward across the first end wall **422** and between the first pins **430** thereon to absorb more heat before entering the fluid channels **174'**. The fluid can then flow through the fluid channels **174'** to absorb more heat from the stator **118'**. The fluid can then flow from the fluid channels **174'** radially outward across the second end wall **462** and between the second pins **470** thereon to absorb more heat. The fluid can then flow axially around the second outer wall **458** and radially inward across the second end wall **466** and between the second pins **470** thereon to absorb more heat. The fluid can then flow through the outlet port **250'** to the heat exchanger **258'**, where the heat **262'** can be transferred from the fluid to a heat sink (e.g., the atmosphere).

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

What is claimed is:

**1**. An electric motor comprising:

a stator body defining a rotor bore and a plurality of fluid channels;

a plurality of electrically conductive windings forming a plurality of first winding loops extending axially outward from a first axial end of the stator body;

a first end cap coupled to the first axial end of the stator body, the first end cap including a first wall and a plurality of first pins, the first wall disposed between the first winding loops and the fluid channels, the first pins extending from a side of the first wall that is opposite the first winding loops; and

wherein the first pins extend radially outward from the first wall; and

wherein the first pins extend radially outward of a radially inward-most part of the fluid channels.

**2**. The electric motor of claim **1**, further comprising a second end cap, wherein the plurality of electrically conductive windings form a plurality of second winding loops extending axially outward from a second axial end of the stator body, wherein the second end cap is coupled to the second axial end of the stator body and includes a second wall and a plurality of second pins, the second wall being disposed between the second winding loops and the fluid channels, the second pins extending from a side of the second wall that is opposite the second winding loops, and wherein the second pins extend radially outward from the second wall and extend radially outward of a radially inward-most part of the fluid channels.

**3**. An electric motor comprising:

a stator body defining a rotor bore and a plurality of fluid channels;

a plurality of electrically conductive windings forming a plurality of first winding loops extending axially outward from a first axial end of the stator body;

a first end cap coupled to the first axial end of the stator body, the first end cap including a first wall and a plurality of first pins, the first wall disposed between the first winding loops and the fluid channels, the first pins extending from a side of the first wall that is opposite the first winding loops; and

wherein the first winding loops extend radially outward of a radially inward-most part of the fluid channels; and

wherein the first wall includes a first annular body and wherein the first pins extend axially from the first annular body in a direction toward the stator body.

**4**. The electric motor of claim **3**, wherein the first winding loops are encased in a thermally conductive but electrically insulating resin that contacts the first wall.

**5**. The electric motor of claim **3**, wherein the first wall includes a second annular body and wherein the first pins extend axially from the second annular body in the direction away from the stator body.

**6**. The electric motor of claim **3**, further comprising a second end cap coupled to a second axial end of the stator body, wherein the plurality of electrically conductive windings form a plurality of second winding loops that extend axially outward from the second axial end of the stator body, wherein the second end cap includes a second wall and a plurality of second pins, the second wall being disposed radially between the second winding loops and the fluid channels, the second pins extending from a side of the second wall that is opposite the second winding loops, the second pins extending into a flow path into or exiting the fluid channels in the stator body.

**7**. The electric motor of claim **6**, wherein the second wall includes a third annular body, the second pins extending axially from the third annular body in a direction toward the stator body.

**8**. The electric motor of claim **7**, wherein the second wall includes a fourth annular body, wherein the second pins extend axially from the fourth annular body in the direction away from the stator body.

**9**. The electric motor of claim **6**, wherein the second wall includes a third annular body and a fourth annular body coupled to the third annular body to define a second winding cavity, the second winding loops being disposed within the second winding cavity, the second pins extending axially from the second annular body in a direction away from the stator body.

**10**. An electric motor comprising:

a stator body defining a rotor bore and a plurality of fluid channels;

a plurality of electrically conductive windings forming a plurality of first winding loops extending axially outward from a first axial end of the stator body;

a first end cap coupled to the first axial end of the stator body, the first end cap including a first wall and a plurality of first pins, the first wall disposed between the first winding loops and the fluid channels, the first pins extending from a side of the first wall that is opposite the first winding loops; and

wherein the first winding loops extend radially outward of a radially inward-most part of the fluid channels; and

wherein the first wall includes a first annular body and a second annular body coupled to the first annular body to define a first winding cavity, the first winding loops being disposed within the first winding cavity.

**11**. The electric motor of claim **10**, wherein the first winding loops are encased in a thermally conductive but electrically insulating resin that contacts the first wall.

**12**. The electric motor of claim **10**, wherein the first pins extend axially in the direction toward the stator body from the first annular body, or the second annular body in a direction away from the stator body.

**13**. The electric motor of claim **10**, further comprising a second end cap coupled to a second axial end of the stator body, wherein the plurality of electrically conductive windings form a plurality of second winding loops that extend axially outward from the second axial end of the stator body, wherein the second end cap includes a second wall and a plurality of second pins, the second wall being disposed in a radial direction from a central axis of the rotor bore between the second winding loops and the fluid channels, the second pins extending from a side of the second wall that is opposite the second winding loops, the second pins extending into a flow path into or exiting the fluid channels in the stator body.

**14**. The electric motor of claim **13**, wherein the second wall includes a third annular body and a fourth annular body coupled to the third annular body to define a second winding cavity, the second winding loops being disposed within the second winding cavity.

**15**. The electric motor of claim **14**, wherein the second pins extend axially in the direction toward the stator body from the third annular body and axially in the direction away from the stator body from the fourth annular body.

**16**. The electric motor of claim **15**, wherein the second wall includes a third annular body and a fourth annular body coupled to the third annular body to define a second winding cavity, the second winding loops being disposed within the second winding cavity, the second pins extending axially from the second annular body in a direction away from the stator body.

**17**. An electric motor comprising:

a stator body defining a rotor bore and a plurality of fluid channels;

a plurality of electrically conductive windings forming a plurality of first winding loops extending axially outward from a first axial end of the stator body; and

a first end cap coupled to the first axial end of the stator body, the first end cap including a first wall, the first end cap defining a first winding cavity separated from fluid communication with the fluid channels by the first wall, the first winding loops being disposed within the first winding cavity;

wherein the first winding loops extend radially outward of a radially inward-most part of the fluid channels.

**18**. The electric motor of claim **17**, wherein the first end cap includes a plurality of first pins that extend radially outward from the first wall.

**19**. The electric motor of claim **18**, wherein the first pins extend radially outward of a radially inward-most part of the fluid channels.

**20**. The electric motor of claim **17**, wherein the first end cap includes a plurality of first pins that extend from the first wall, wherein the first wall includes a first annular body and a second annular body coupled to the first annular body to define the first winding cavity, the first pins extending axially from at least one of: the first annular body in a direction toward the stator body, and the second annular body in a direction away from the stator body.

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